Developmental History of a New Family of Subscale, Convertible, High Performance UAVs

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Micro Aerial Vehicles -- Unmet Technological requirements
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Report Documentation Page

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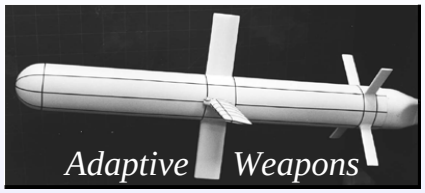
Outline



1989 - ‘96 Enabling Materials and Experience

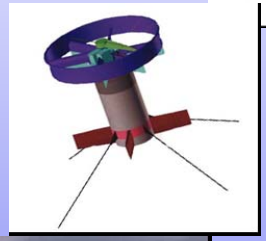
1994 - ‘97 The First DoD MAV

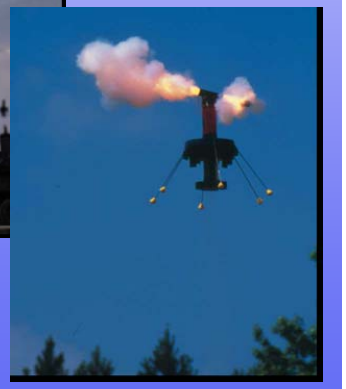
1998 - ‘00 DARPA’s MOUT MAVs

2001 - ‘03 Convertible Military MiAVs

2003 X/YQ-138 Handoff to Industry


Kolbri


LuMAV


YQ-138 Weapon Firing

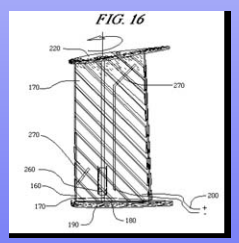
1989 - ‘96 Enabling Materials and Experience

1989

1st DAP missile fin study

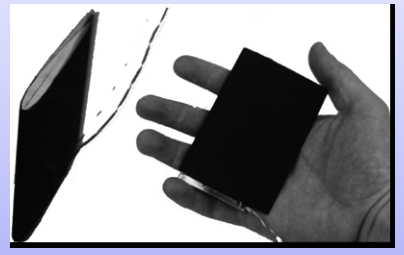
1990

1st twist-active adaptive wing built & bench tested
(±0.8° static twist deflections)



1991

1st prototype pitch-active missile fin
(±5° static deflections)

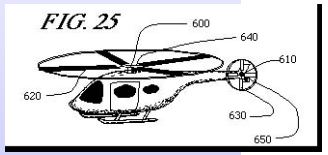


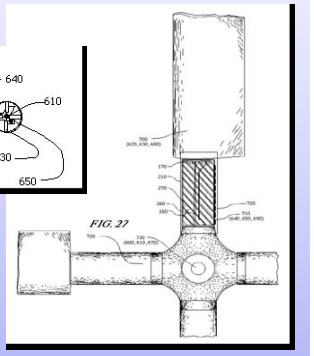
1992

1st torque-plate rotor built (±5° static deflections)

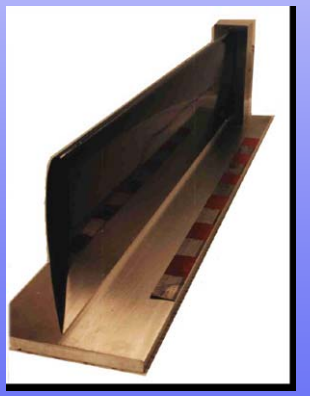
1993

GD licenses DAP technology





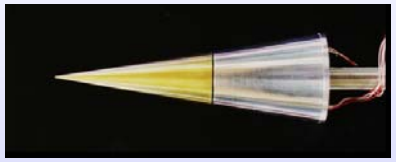
1st twist-active rotor blade assembled & tested



Directional Attachment invented to generate twist deflections in aerodynamic surfaces

1989 - '96 Enabling Materials and Experience

Gamara, the first helicopter to use adaptive materials for all flight control

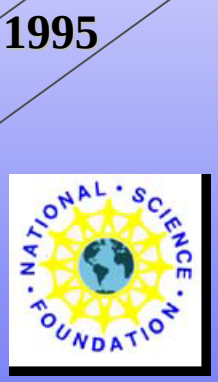


1994

NSF sponsors UAV & DAP rotor work

1995

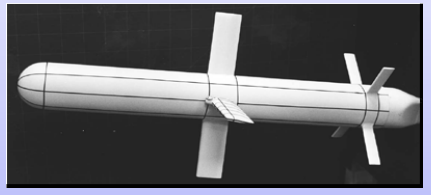
Piezoceramic lamina hardening techniques invented for Barrel Launched Adaptive Munition (BLAM) program



DAP torque-plate rotor demonstrates ±8° static and dynamic deflections at up to 2.5/rev on Froude & Mach scaled rotors

1996

Adaptive TOW-2B



Adaptive gravity weapons

Mothra, the first aircraft to use adaptive materials for all flight control

1994 - '97 The First DoD MAV

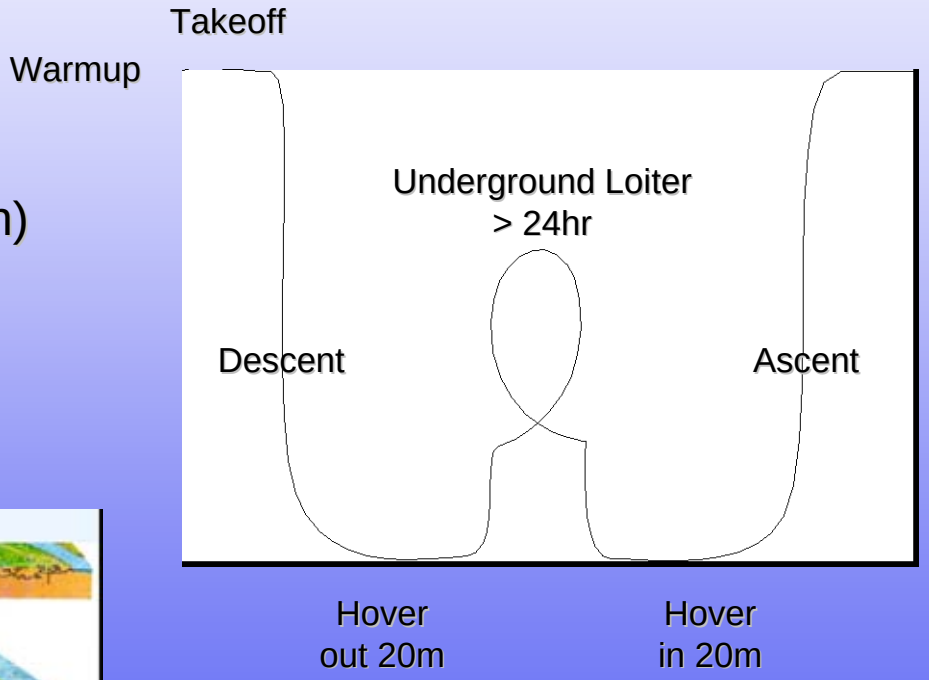
Sponsor: DoD CounterDrug Technology Office

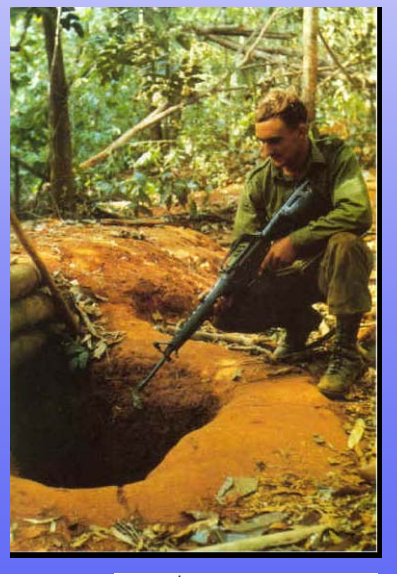
Mission Challenge: counterdrug agents and animals die in border tunnels

Mission Specification:

- Max. 6" (15cm) dia. rotor
- Max. Range: 20m
- Max. Endurance: >24hr
- T/O distance: VTOL
- Max flight speed: 2mph (3kph)
- Coms link: hard wire
- Sensor: B/W 0.1 lux
- Stationkeeping: 5cm
- No chemical emissions

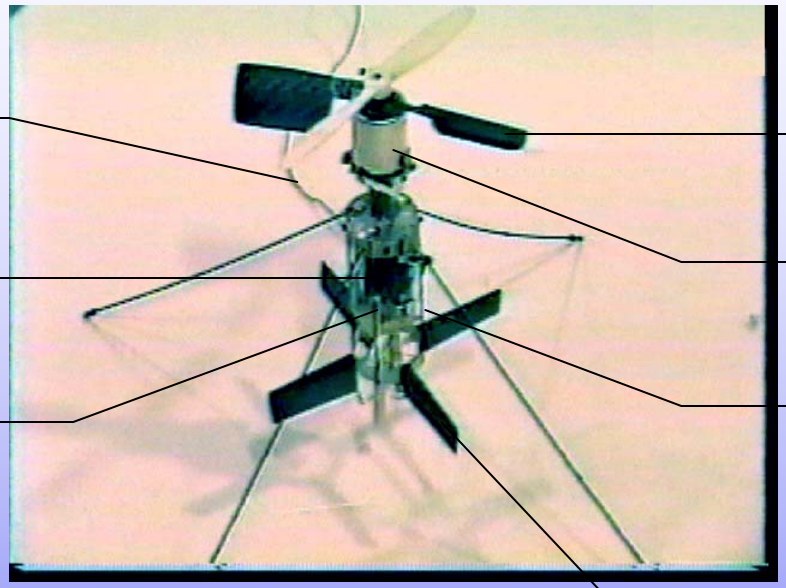
Mission Profile:





1994 - ‘97 The First DoD MAV

Kolibri

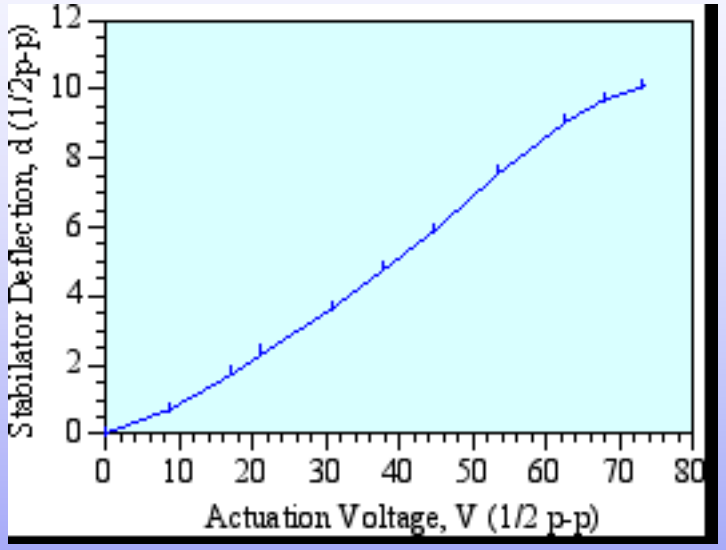


1st Flight September 1997

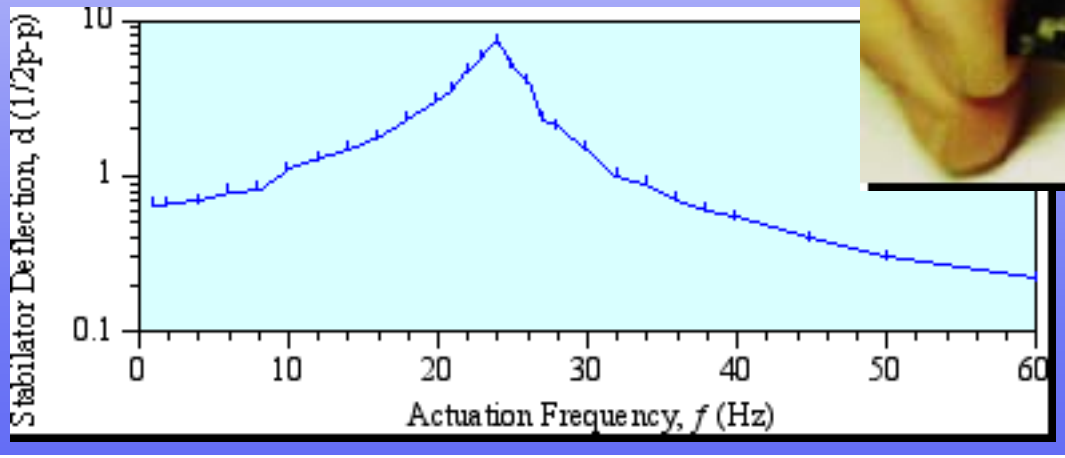
Kolibri Airborne Camera View

1994 - '97 The First DoD MAV

Enabling Technology: *High Speed Piezoelectric Stabilators*



- first natural frequency in pitch: 23 Hz
- pitch corner frequency: 47 Hz
- max power consumption: 14 mW
- max. static deflections: ±11°
- total mass 5.2g
- actuator mass: 380 mg



1998 - 2000 DARPA's MOUT MAVs

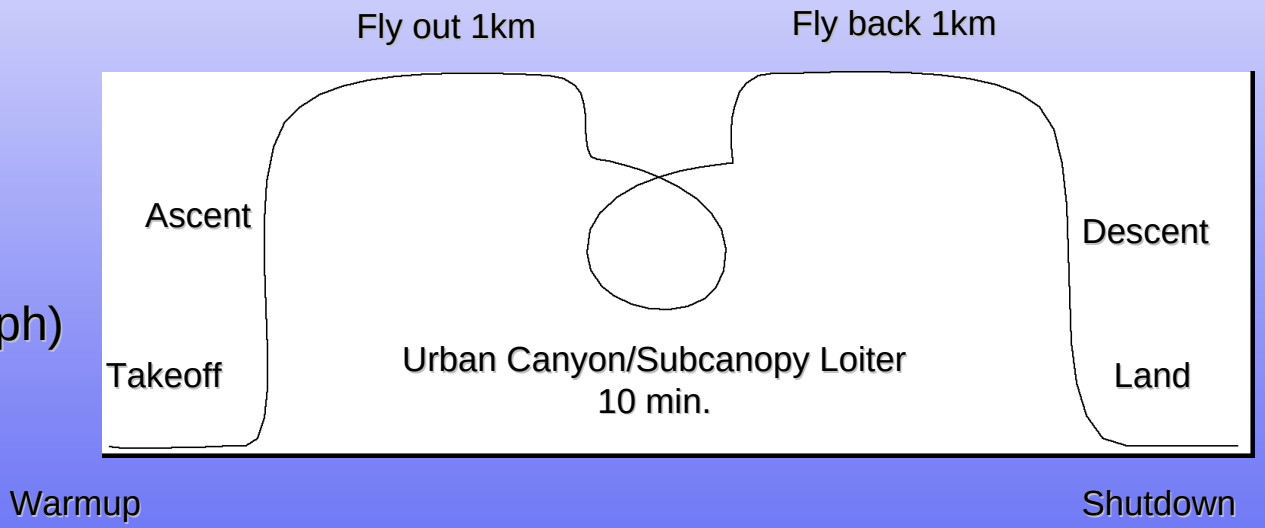
Mission Challenge: reconnaissance in urban and subcanopy environments

> *"Military Operations in Urban Terrain is one of the top priorities for the DoD."*
>
> *-Lt. Gen. Bruce Knutson, USMC Nov. 1999*

Mission Specification:

- Max. 6" (15cm) dia. rotor
- Max. Range: 1km
- Max. Endurance: 20 min.
- All weather capable
- 15g wall strike
- T/O distance: n/a
- Max flight speed: 30 mph (48kph)
- Com link: RF
- Flight modes: 1st, 3rd person
- Sensor: B/W 0.1 lux

Mission Profile:



1998 - 2000 DARPA's MOUT MAVs

Motivation:

"2/3 of eligible targets in the Balkans went undetected, let alone unengaged because of our reconnaissance deficiencies."

-Lt. Gen. Bruce Knutson, USMC Nov. 1999

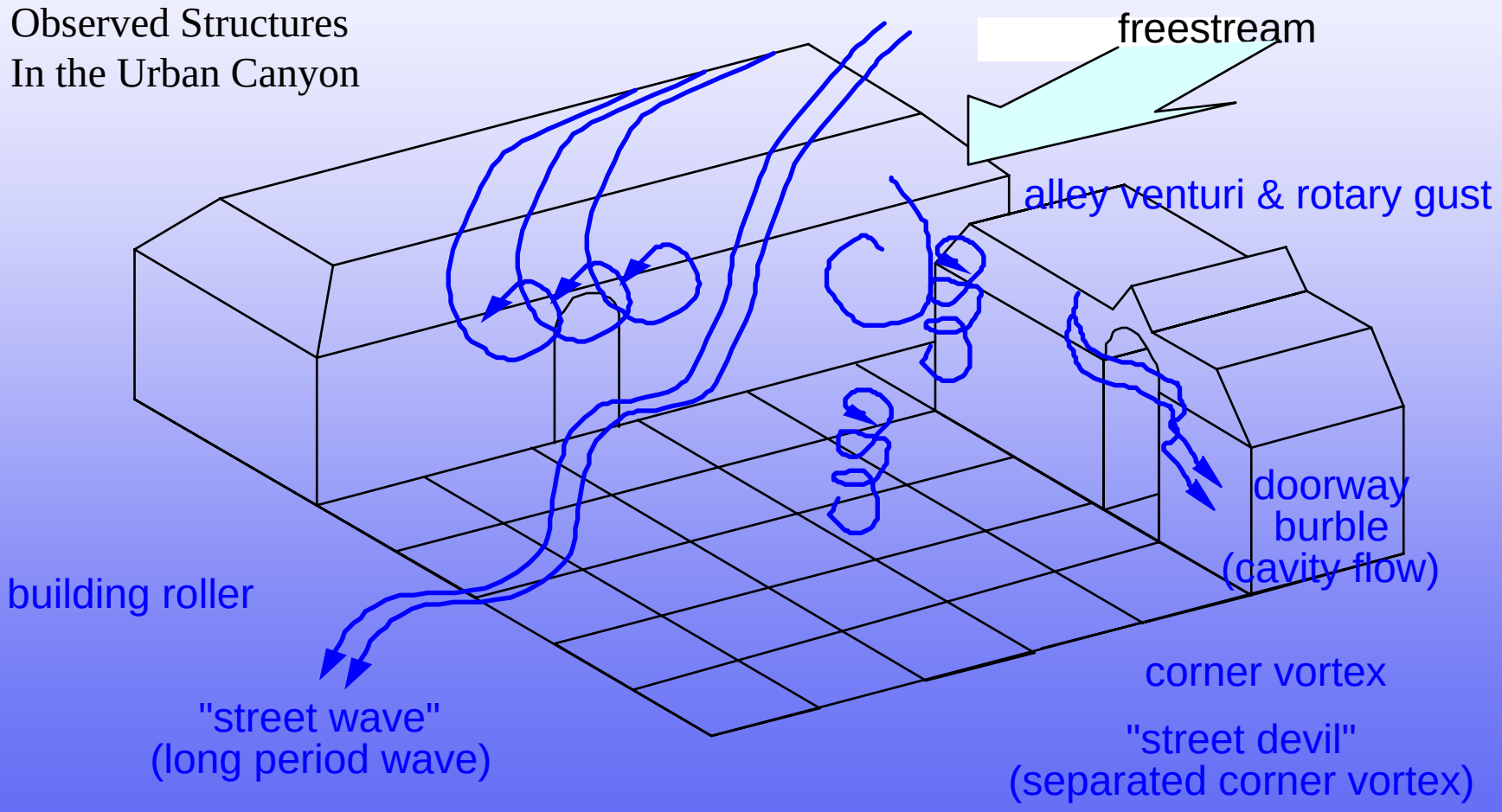
Current UAVs offer monocular situational awareness with only one general view -- from above.

Panocular situational awareness is necessary in the modern battlefield.

M998 HMMWV Aerial Detection Exercise, Alabama July 1998

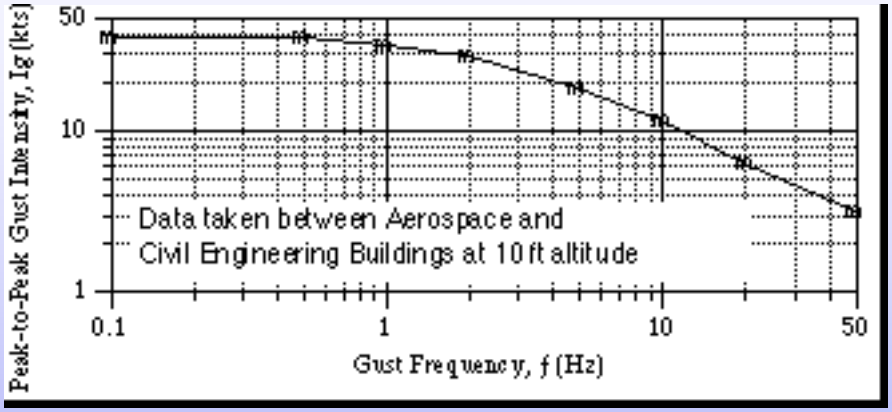
1998 - 2000 DARPA's MOUT MAVs

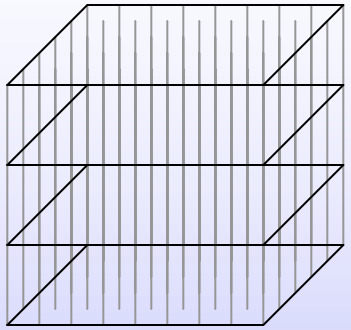
Environmental Survey:



1998 - 2000 DARPA's MOUT MAVs

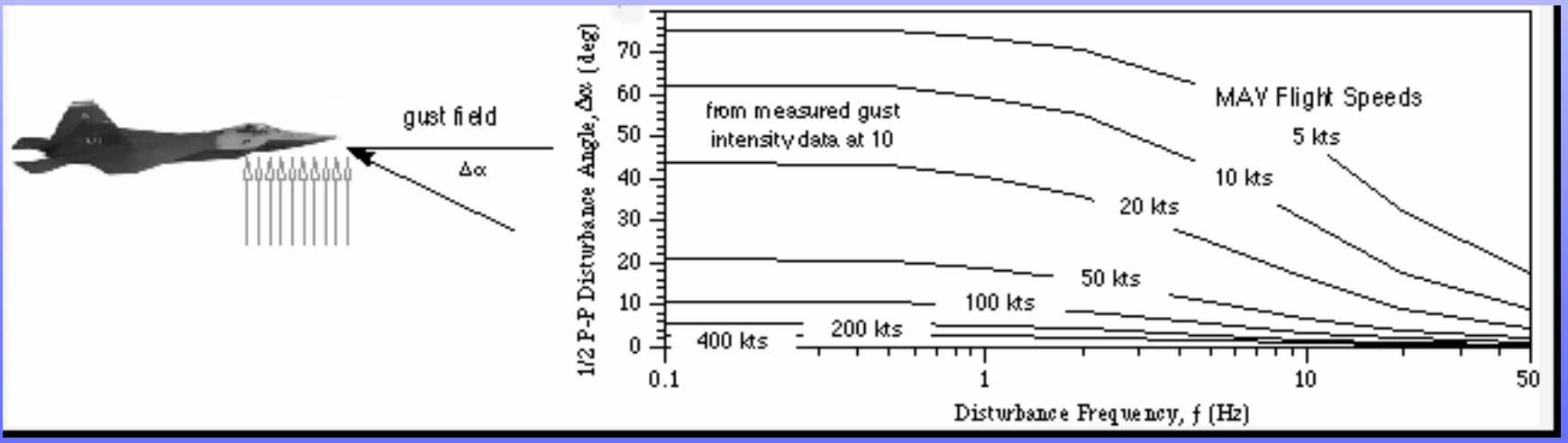
MOUT & Subcanopy MAV Configuration Selection





Isotropic Gust Grid:
363 sample points

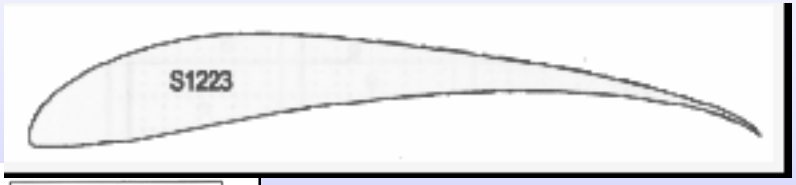
100 ft x 100 ft x 30 ft high (30m x 30m x 9m high)
1 min. per point, 10 days of sampling
Blue sky sampling days only

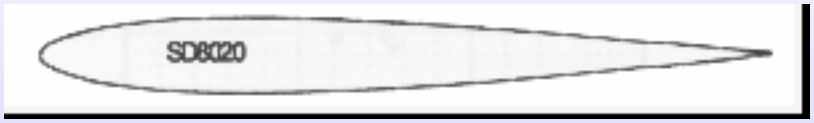


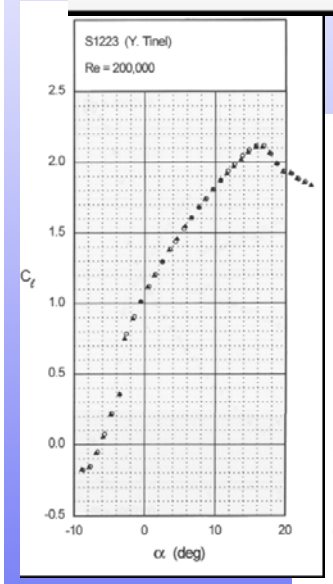
1998 - 2000 DARPA's MOUT MAVs

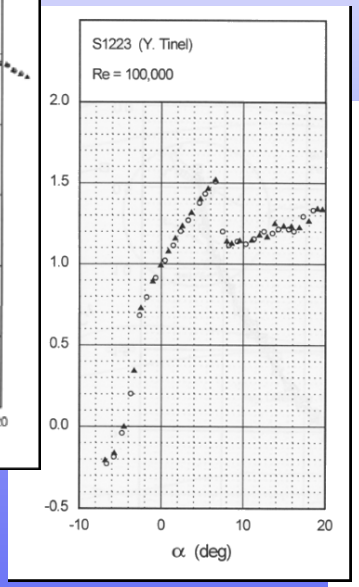
MOUT & Subcanopy MAV Configuration Selection

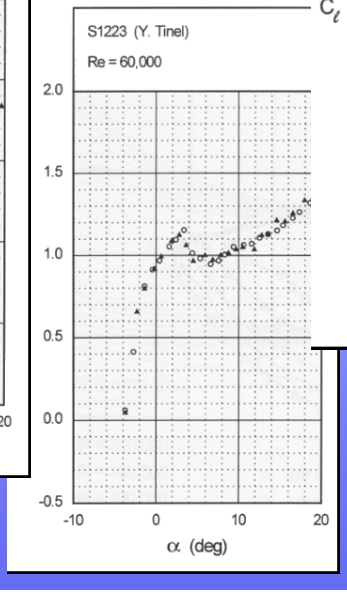
Aerodynamics Challenges: Low C_{lmax} at Low Rn… gusts… and rain

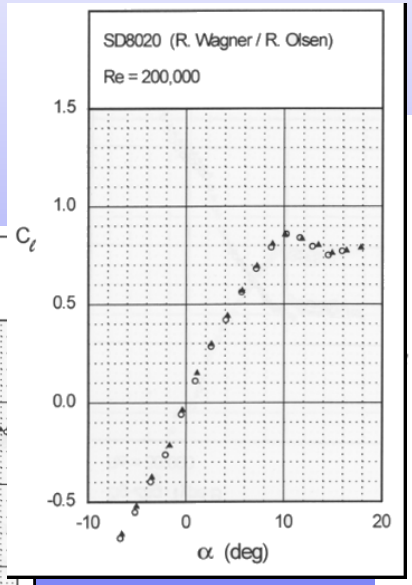


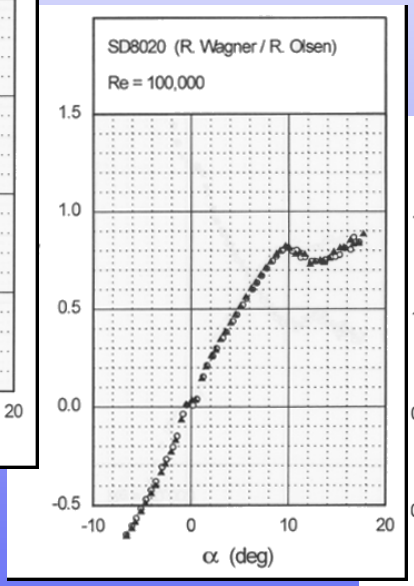


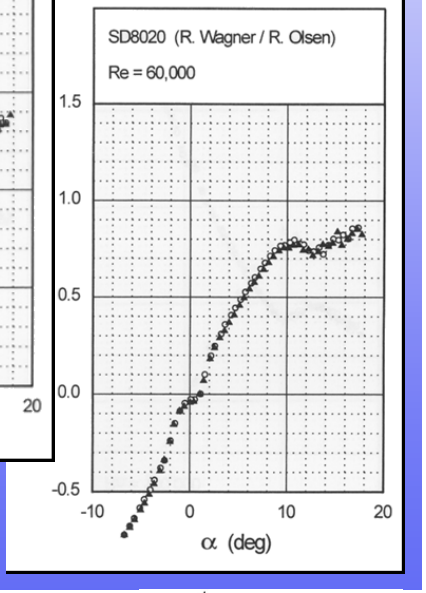










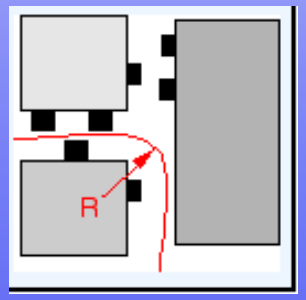


1998 - 2000 DARPA's MOUT MAVs

MOUT & Subcanopy MAV Configuration Selection: Turn Radii Required

Urban Setting Survey

200 intersections in Groningen, Netherlands within 1km of Station Nord

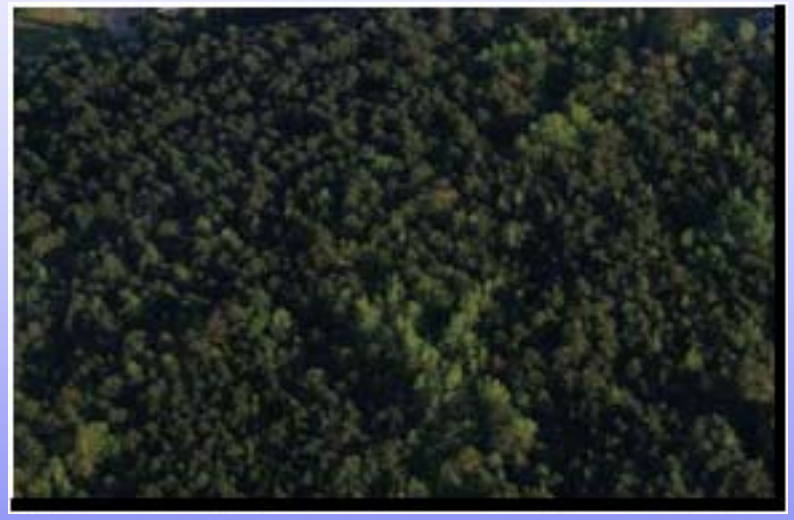


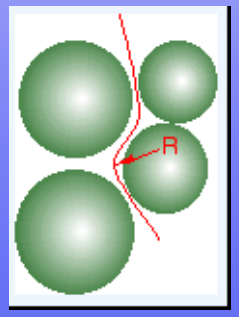
Aircraft Turn Radii

-1 Std Dev.	Average	+1 Std Dev.
6.1ft	8.7ft	14.4ft
1.9m	2.7m	4.4m

Subcanopy Survey

200 trees in the Tuskegee National Forest along Bartram National Recreation Trail





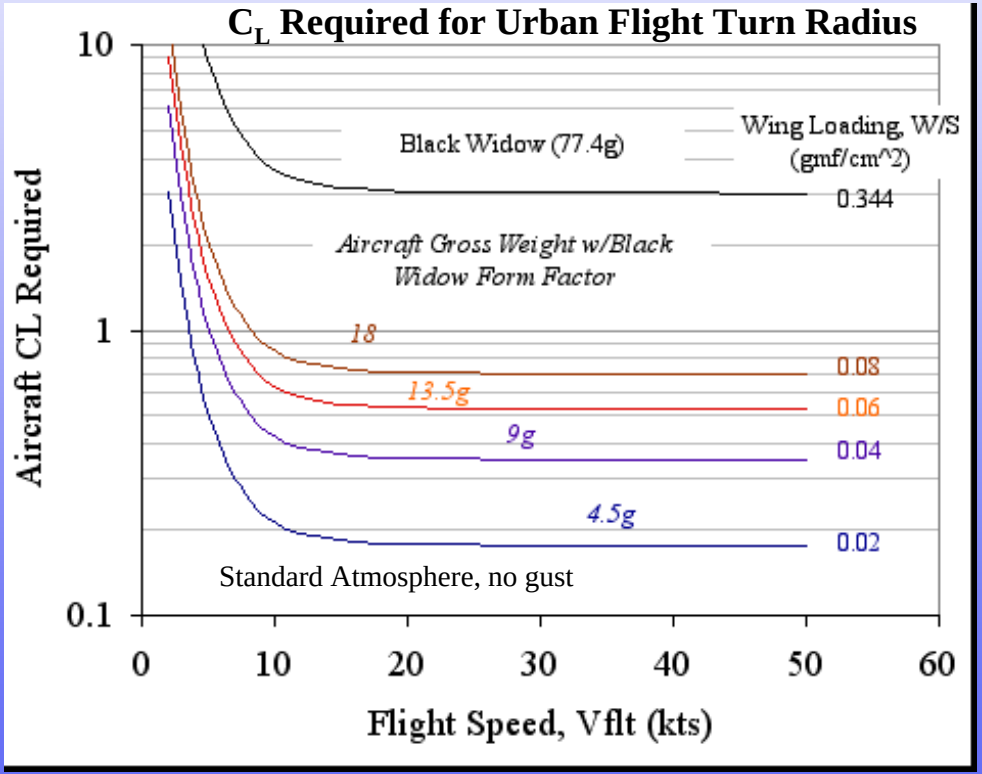
Aircraft Turn Radii

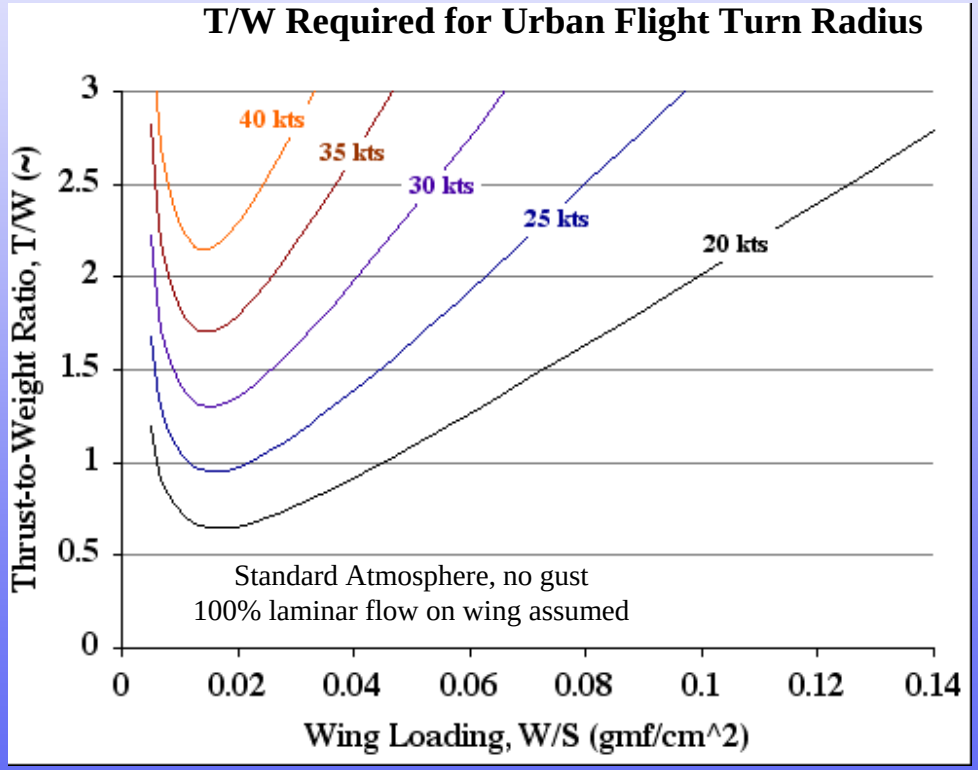
-1 Std Dev.	Average	+1 Std Dev.
8.8ft	14.7ft	32.9ft
2.7m	4.5m	10m

1998 - 2000 DARPA's MOUT MAVs

MOUT & Subcanopy MAV Configuration Selection:

- **CURRENT FIXED-WING MAVs CANNOT MAKE THE TURNS IN URBAN TERRAIN**
- **FUTURE FIXED-WING MAVS REQUIRE T/W >1 TO NAVIGATE URBAN TERRAIN**





1998 - 2000 DARPA's MOUT MAVs

MOUT & Subcanopy MAV Configuration Selection: COLEOPTER

LuMAV-2
DARPA TTO 1998-1999

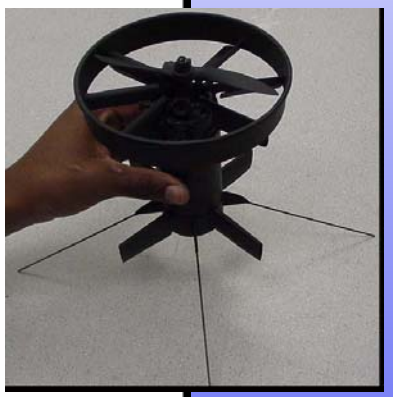
Bench, Hover Stand and Wind Tunnel Test Article

Demonstrated:
- Aerodynamic Characteristics
- Power Requirements

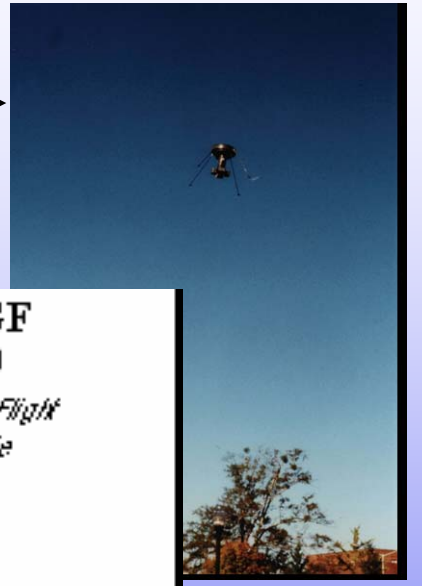
MultiDisciplinary Optimization

LuMAV-2AS/GF
DARPA TTO 1998-2000

6" (15cm) Free-Flight Rotary-Wing Flight Vehicle



Demonstrated:
- 20 min. hover
- 22 kt flight speed
- 6 oz (171g) payload
- Perch Capability
- Indoor & Outdoor Flight
- Graphite-Epoxy Structure
- Stationkeeping with ±8 kt gusts
- Muffling to Background Levels @ 15m
- In-Flight Full Color & Low Light Video Link
- 1st Flight July 1999



LuMAV-3AS/GF
DARPA TTO 2000

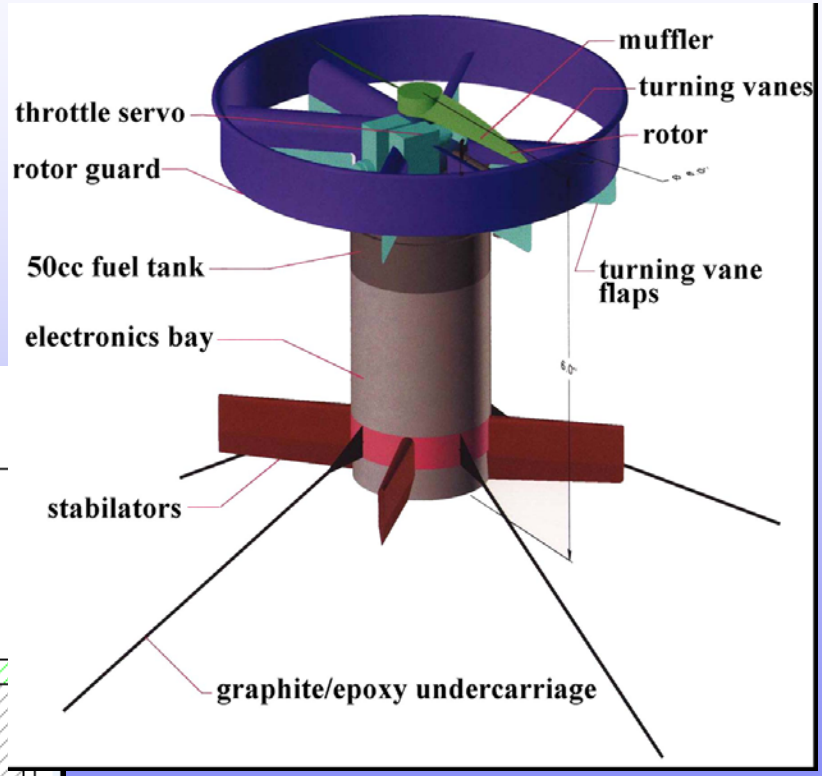
6" (15cm) Recoverable Free-Flight Rotary-Wing Flight Vehicle

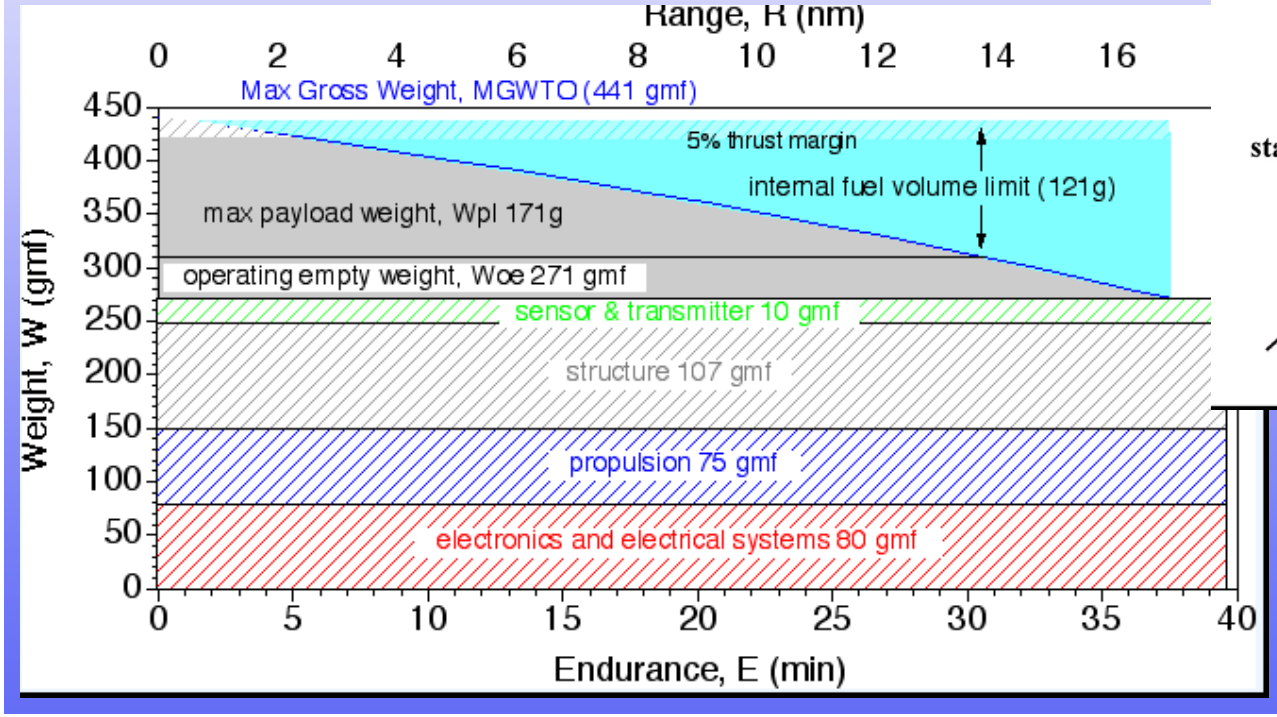
Demonstrating:
- 20 min. hover
- 32 kt flight speed
- 6 oz (171g) payload
- Perch Capability
- Indoor & Outdoor Flight
- Flight in rain to 14.5 in/hr, ±14 kts
- Urban Canyon Surveillance
- High Control Authority Empennage
- Improved Graphite-Epoxy Structure
- Stationkeeping with ±18 kt gusts
- Muffling to Background Levels @ 15m
- In-Flight Full Color & Low Light Video Link
- 1st Flight May 2000

1998 - 2000 DARPA's MOUT MAVs

MultiDisciplinary Optimization Performed on:

- Structures
- Aerodynamics
- S&C
- Propulsion



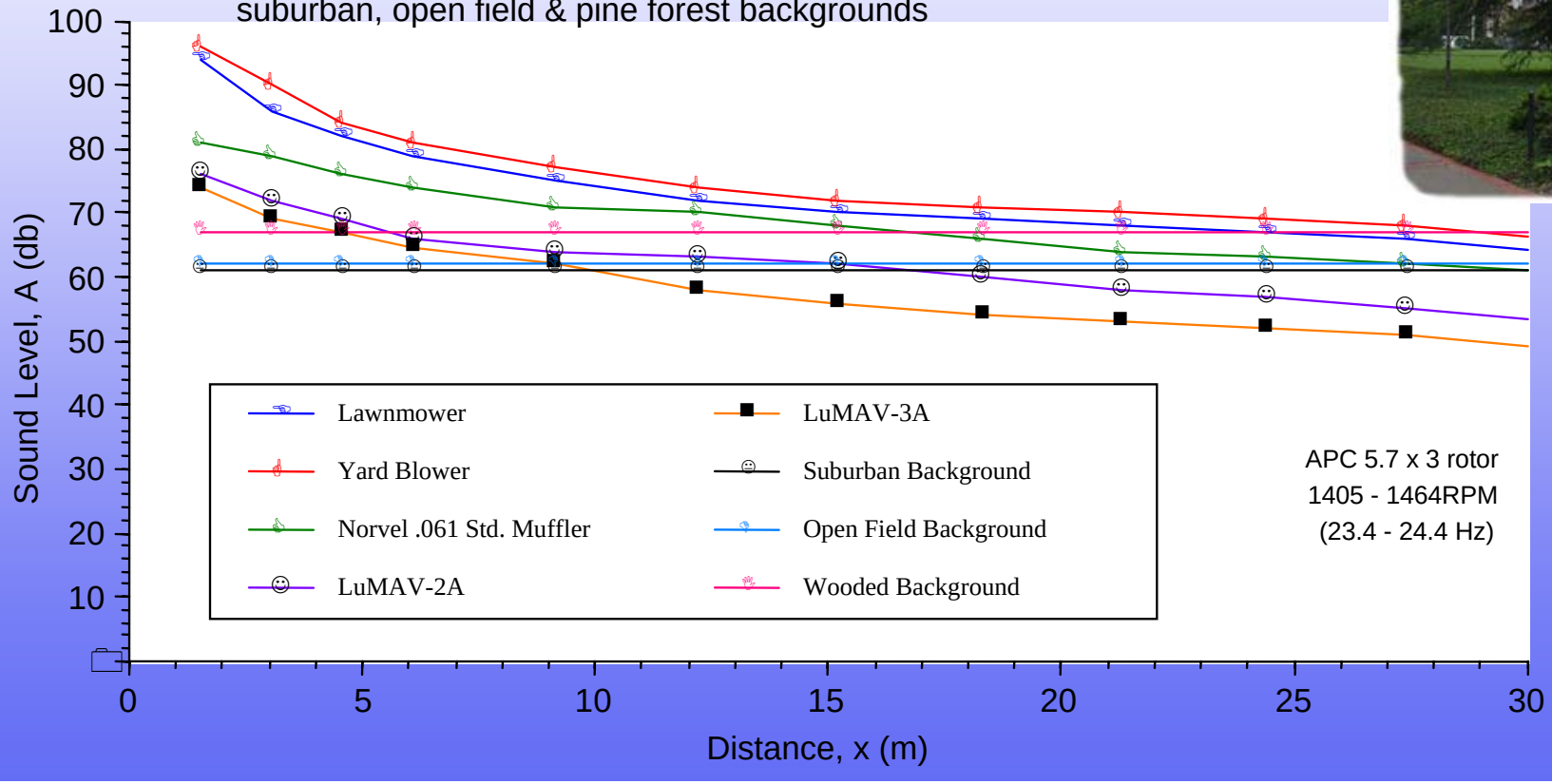


1998 - 2000 DARPA's MOUT MAVs

LuMAV Testing

acoustic signature

test conditons:
72 - 78°F day, 65% humidity
winds 3 - 6 kts & variable, 9:00 - 11:00 am
testing conducted: East Central Alabama in March
suburban, open field & pine forest backgrounds



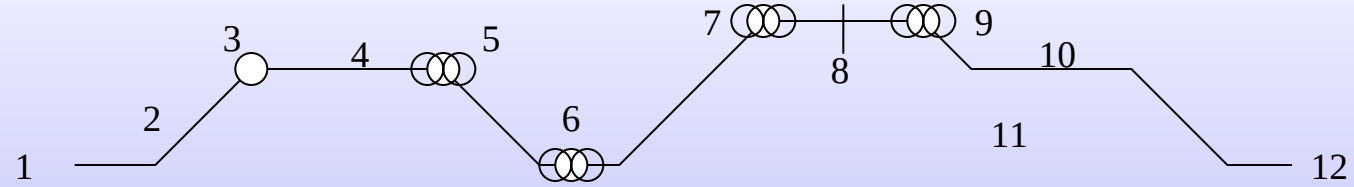
APC 5.7 x 3 rotor
1405 - 1464RPM
(23.4 - 24.4 Hz)

2001 - '03 Convertible MILITARY MiAVs

Mission Challenge:
MOUT Capable MILITARY Subscale UAV with High Dash Speed & Efficient Loiter

"We want a subscale UAV that can do it all." *-Mr. Serh Ghee Lim, President, Singapore Technologies Aerospace Corp.*

XQ-138 Design Mission:



Mission Stage	Endurance (min)	Elapsed Time (min)	Mission Stage	Endurance (min)	Elapsed Time (min)
1. Startup	1.0	1.0	7. Climb & HOGE 5 min	5.0	33.5
2. VTO & Climb	0.5	1.5	8. Release & HOGE 5 min	5.0	38.5
3. Xition	0.5	2.0	9. Xition & Descent	0.5	39.0
4. Cruise, 10 km, 50 kts	6.5	8.5	10. Cruise, 10 km, 50 kts	6.5	45.5
5. Xition & HOGE 10 min	10.0	18.5	11. Xition	0.5	46.0
6. Desc. & HOGE 10 min	10.0	28.5	12. VL & Shut-down	1.0	47.0

Mission Specification:

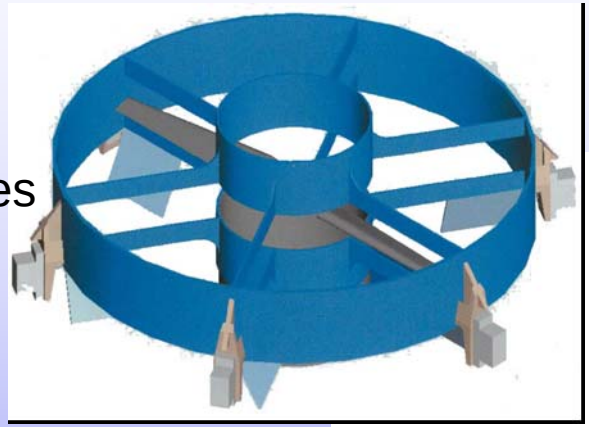
- Max. weight: 6 lb (2.7kg)
- All weather capable
- 25 kt gust penetration
- Com link: RF
- Dash speed: 80mph (130kph)
- Flight modes: 1st, 3rd person, fully autonomous w/waypoint navigation
- Mission Range: 10km
- 12"/hr (31cm/hr) rain
- 15g MOUT wall strike
- 500g P/L
- Sensors: B/W 0.001 lux, Color 0.1 lux, FLIR
- Design Mission Duration: 47 min.
- 100°F (38°C), 100% humidity
- Combat shotgun resistant @5m
- T/O distance: n/a

2001 - ‘03 Convertible MILITARY MiAVs

XQ-138 Design: MDO using best currently available technology

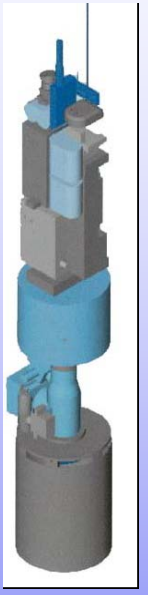
Rotor Guard

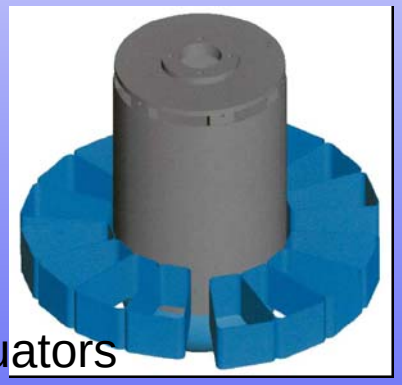
- turning vane flap servos
- electrical & fuel feed lines
- turning vanes
- turning vane flaps
- rotor



Upper Fuselage

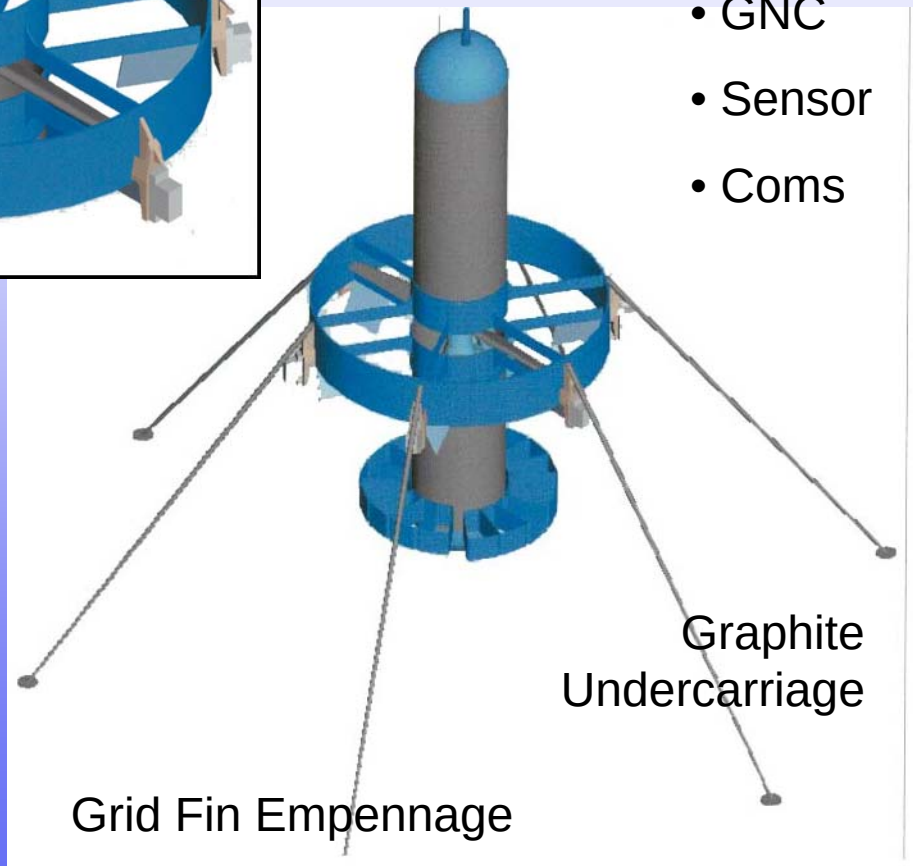
- fuel
- GNC
- Sensor
- Coms





Lower Fuselage

- powerplant
- empennage actuators
- muffler assembly

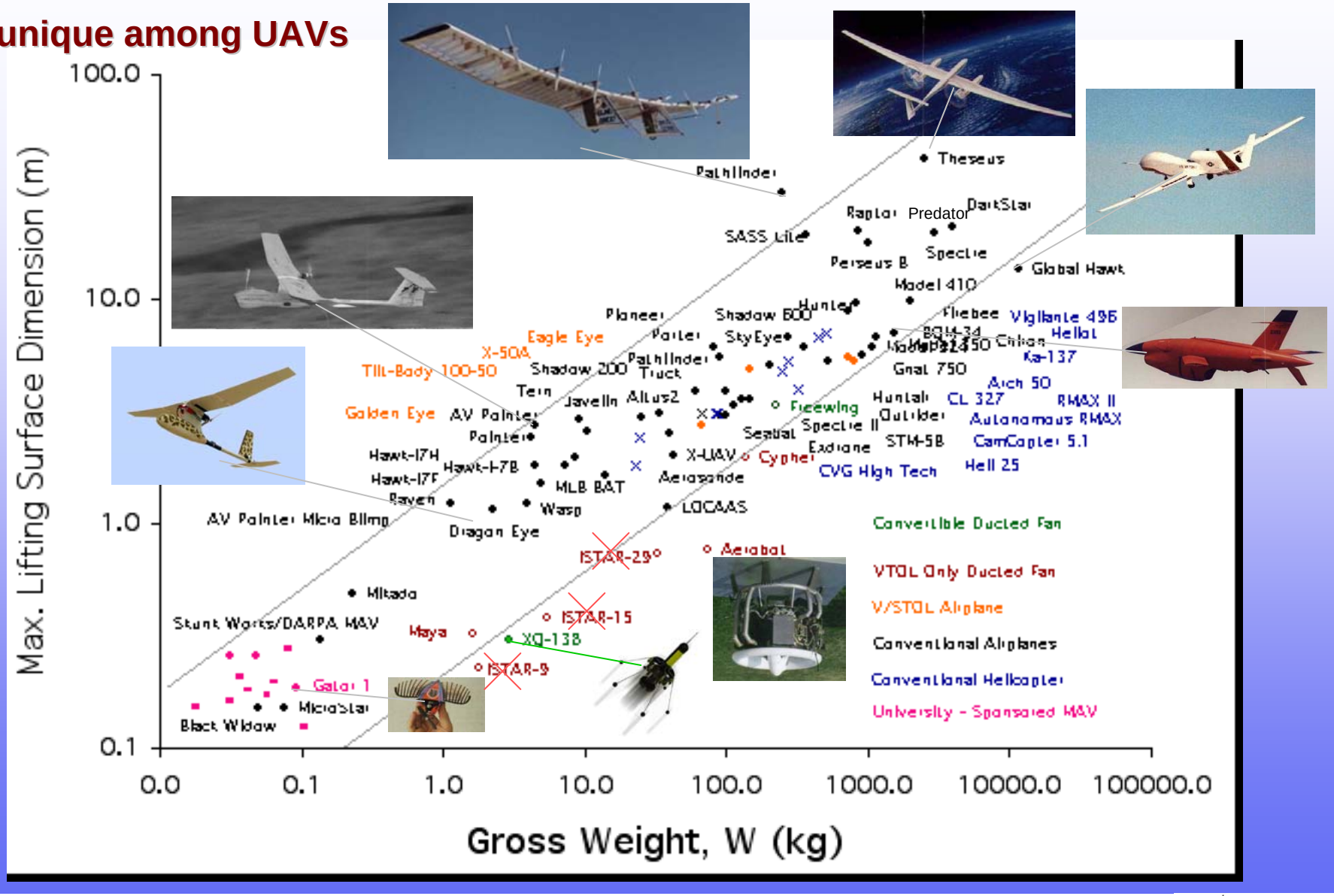


Graphite Undercarriage

Grid Fin Empennage

2001 - '03 Convertible MILITARY MiAVs

XQ-138: unique among UAVs



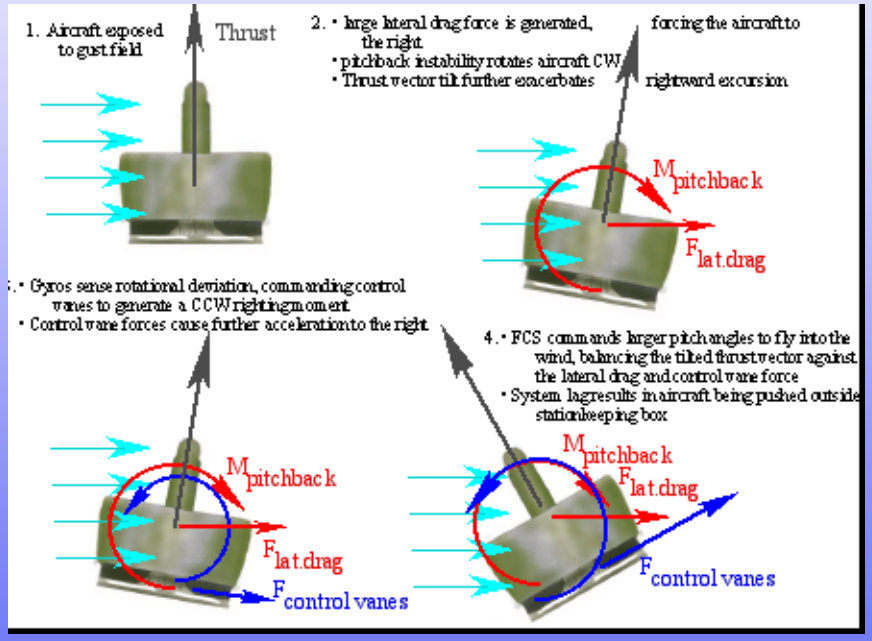
2001 - '03 Convertible MILITARY MiAVs

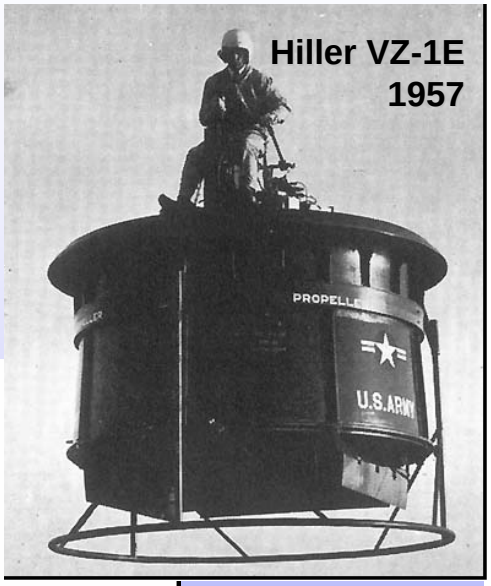
Coleopter Pitchback Instability: 50 years of Experience

"We didn't have the control authority needed for the prevailing conditions."

Gary Downs, Director Allied UAV Systems following catastrophic crash of the iSTAR at Ft. Eustis in light but gusty wind conditions. 10 September 2003 http://www.uvonline.com

Coleopter Pitchback Instability explained in OAV Proposal to DARPA 1/01





Hiller VZ-1 1954

"Unfortunately, this effect limited the forward speed to a mere 26 kph (16 mph) and caused erratic handling in windy conditions." Smithsonian Air and Space Museum on the Hiller VZ-1 aircraft http://www.nasm.si.edu/nasm/aero/aircraft/hiller_vz1.htm

2001 - '03 Convertible MILITARY MiAVs

XQ-138 Flight Demonstration from LAV at Redstone Arsenal and Eglin AFB
Strong Gusty Conditions to 26 kts April - May 2002

1. Aircraft loaded & preflighted

2. Aircraft Release

3. Vertical Ejection @ ~ 10 ft/s (~ 3m/s)

4. Clearing Launcher

5. Transition

6. Flyaway

26 kt gusting winds @ Eglin Hellfire Range

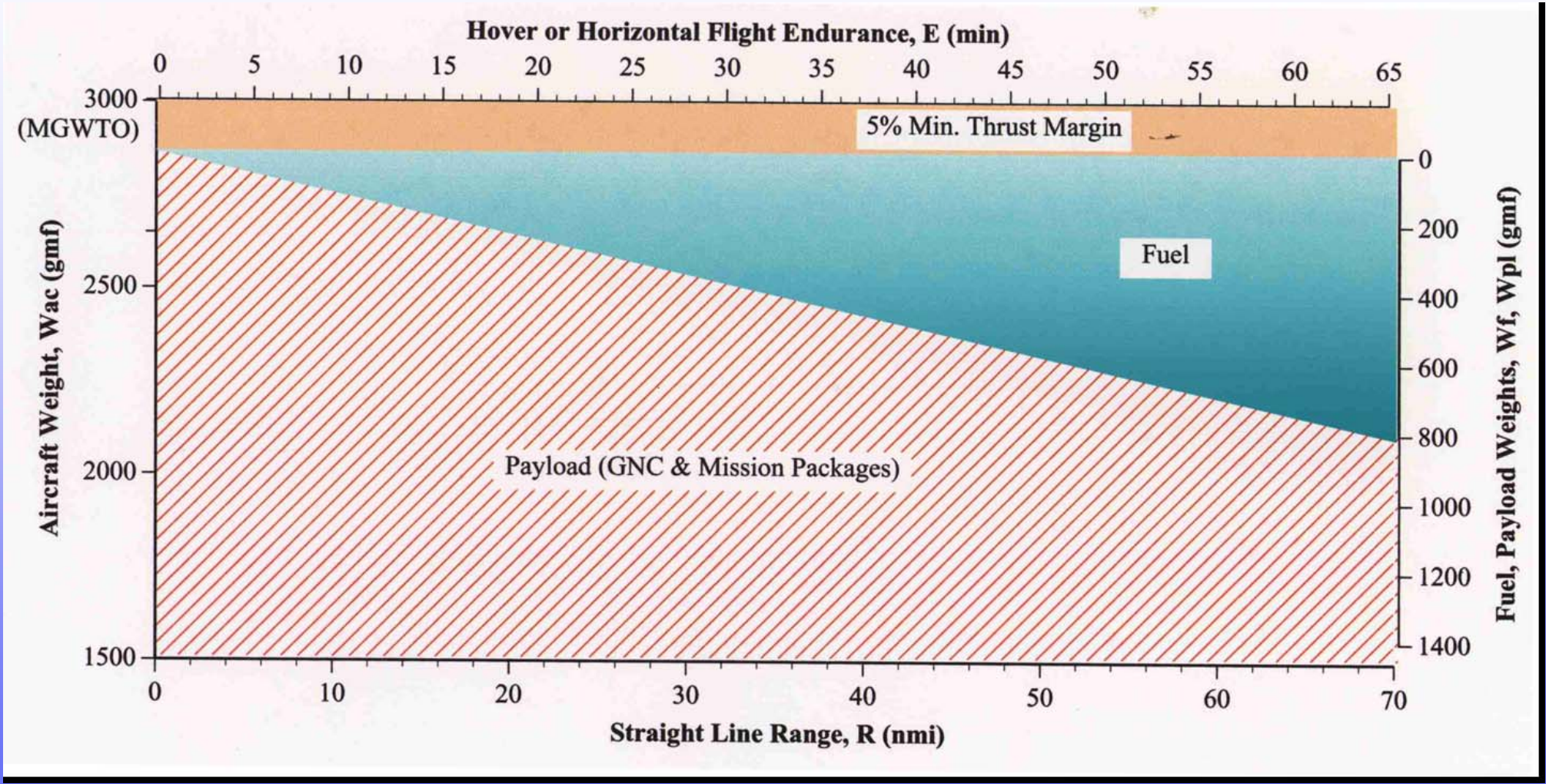
2001 - ‘03 Convertible MILITARY MiAVs

Autonomy Package Development 6/02 - 6/03

Demonstrated multiple waypoint navigation in hover mode flight

Payload Delivery Testing 7/03

2001 - ‘03 Convertible MILITARY MiAVs

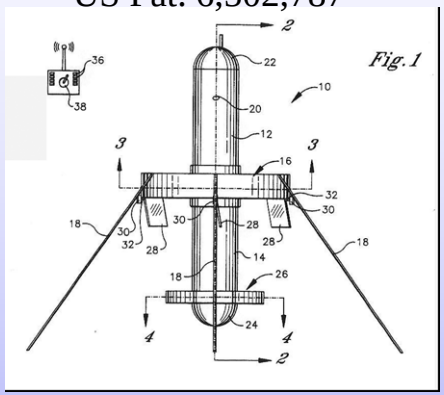


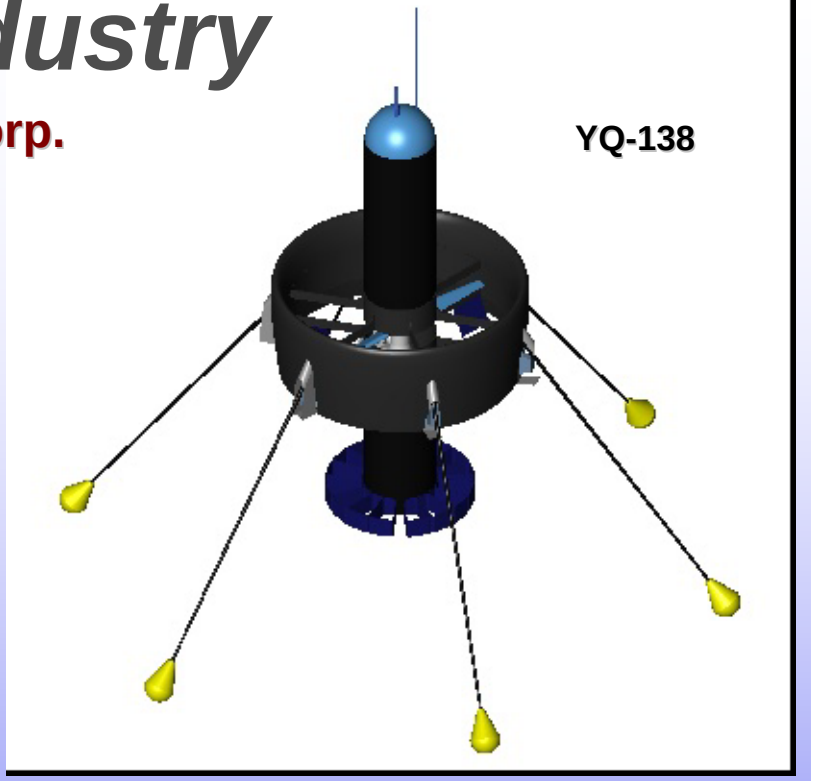
2003 Handoff to Industry

Purchased by Singapore Technologies Aerospace Corp.

Limited rate production scheduled 2nd qtr/04

US Pat. 6,502,787





Future variants:

Elastic, modular design = too many to cover